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RADIATION DAMAGE - ELECTRON IMPACT

NASA Research Grant NsG-371

N64-25567

*CODE-1 CAT. 25*

*NASA CR-56838*

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UNPUBLISHED PRELIMINARY DATA

Status Report April 1964

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Theoretical work to date, taking advantage of the broad title of the grant, has been confined to an attempt to correlate theoretical studies of proton induced radiation damage in Germanium, over the range of incident proton energies from 20 Mev to 150 Mev, with the experimental results of Corelli and Fischer (J.E. Fischer and J.C. Corelli, "Carrier Lifetime Studies in Electron (10-55 Mev) and proton (25-110 Mev) Irradiated Germanium," to be published). The emphasis of the work is directed toward the inclusion of nuclear scattering and reactions in predictions of damage. Order of magnitude estimates of the contribution of the scattering alone, using a non-interfering combination of pure Rutherford scattering and "hard sphere" spherically symmetric nuclear potential scattering ( with  $\sigma = 1 \text{ bn}$ ) together with the Kinchen-Pease model of displacement production, yield a reasonable fit to Fischer and Corelli's 20 and 40 ohm-cm Germanium results.

The calculation indicated that inclusion of nuclear events can indeed force sufficient deviations from the Rutherford  $1/E$  law to yield agreement with experiment. The nuclear scattering in the rough calculation was assumed to be isotropic, however, an assumption which weights large energy transfers too heavily. Some more careful exploratory calculations were therefore performed, in which the assumption of isotropic nuclear scattering was relaxed. The scattering formulae given

by Blatt and Weiskopf (Theoretical Nuclear Physics, New York, John Wiley and Sons, 1954, pp. 335 ff) were programmed for the GE-225 computer, and computations performed with the retention of partial waves through  $l=15$ . Good agreement with Fischer and Corelli's data was obtained, but the ionization cut-off required is rather high (0.2 Mev).

Inclusion of an inelastic scattering cross section should allow the use of a lower ionization cut-off. Computations of damage, including inelastic cross sections, with the use of the optical model, are now being undertaken. The ABACUS program (ABACUS-1-C, KAPL report -30-20, Knolls Atomic Power Laboratory, In Press) for computing optical model cross sections has been obtained. The program in its present form is written in the FORTRAN-II language for the Philco -s-2000; it is now being converted to the GE-225.

This work comprises the Ph.D. research of E.A. Saunders.

#### Experimental Work

Substantial progress has been made during this period toward completing the major experimental facility required for this research program. The symmetric 20" radii of curvature electrostatic and magnetic analyzers have been tested as a double-focusing system, and meet the general design specifications. A considerable effort is in progress to complete a coincidence scheme for detecting single ions in a radiation environment. This single aspect of the

work was not envisioned in the original outline of this project. If successful, however, this concept is expected to find important applications in other NASA programs, and hence serious attention to this single experimental development appears desirable.

Because a topic report is anticipated at a later date, this progress report will summarize only the major aspects of experimental work:

#### Magnetic Analyzer

As stated in the first progress report, the magnet is capable of analyzing ions of much higher energy than are anticipated in the present work. Monitoring of the magnetic field strength has been achieved via a nuclear magnetic resonance probe located in a specially constructed "shim". It will be necessary to control the field remotely when the spectrometer is placed in the Linac target room, and an appropriate scheme has been devised. Basically, current control will be used, with the nuclear resonance unit providing merely a read-out (rather than controlling) the frequency corresponding to a precise magnetic field.

Provision for changing the effective radius of curvature by moving the 5-ton magnet on roller bearings, is anticipated for target room operation. This addition is of a minor nature, but appears to be a needed additional feature. No other mechanical changes are anticipated.

### Electrostatic Analyzers in "Z" Lenses

The large electrostatic cylindrical lenses were obtained after a two month delay due to fabrication difficulties from the vendor. These were machined from stainless steel forgings, suitably annealed. It was necessary to obtain special ceramic insulators to complete the electrostatic assembly. We were fortunate in obtaining experimental billets of alumina whose expansion coefficient was precisely known from the G.E. Research Laboratories. Thus it was possible to design and machine the insulating supports, and anticipate the large shrinkage factor (  $\sim 10\%$  ) upon "firing" and hardening. "Firing" after machining in a shop, was done at the Metals and Ceramics Laboratory of G.E. in Schenectady. These hardened ceramics have an exceedingly low vapor pressure, and have shown neither current leakage or voltage breakdown under test.

The "Z" lenses comprise a pair of so-called "einzeln" units made from assemblies of six  $\frac{1}{2}$ " diameter stainless steel machined cylinders. High voltage is applied to the center pair of electrodes; the entire unit provides strong focusing paraxial ions. Tests to date have not been quantitative, but a test has been made with a surface ionization source with a diverging beam of ions. A factor of ten has been observed in the total ion current received by a "faraday-cage" at the detector focal point (compared

to no "Z" focusing)' therefore, these lenses are presumed to be operational.

#### Vacuum System

The main vacuum housing of this spectrometer has met every specification. With a 75 liter ion-pump a pressure of  $1 \times 10^{-7}$  mm Hg is consistently attained. If this pressure can be maintained when the instrument is connected to the Linac drift pipe, there should be a negligible probability for ions undergoing scattering or charge exchange. The detector unit assembly is separately pumped with a 15 liter ion pump, which, to date, pumps only to  $5 \times 10^{-7}$ . This pressure is probably satisfactory, but it may be desirable to add a cold trap.

The connecting section of the Linac drift pipe has also been fabricated - but not tested. Worthy of mention are the indium wire gaskets, which, under 4 months of testing, have been proven to be inexpensive, and reliable for very high vacuum work. Because these gaskets can be made in the laboratory for both rectangular and circular shapes of almost any dimensions, such gaskets should be of interest to others engaged in the design of experimental high vacuum systems. A special large pyrex window, in the "source" section of the spectrometer, has also proven to be quite satisfactory.

#### Performance Testing

Tests are incomplete but the spectrometer appears to meet the general prerequisites for which it was designed.

Specific items of interest are:

1. Ultimate vacuum measured  $8 \times 10^{-8}$  mm Hg
2. Cs-133, and Rb 85,-87 have been analyzed at 10 Kev using a thermal ionization source, and simulated tests have been made of the double-focusing system for ions having a large spread.
3. "Z" focusing lenses are effective in enhancing the total number of collected ions (an order of magnitude increase in current has been observed).
4. Counting of single ions has been achieved with a modified phototube (#5810 A).
5. Time-of-flight techniques for differentiating between surface and substrate atoms, will use existing available instrumentation.

The decision to proceed with the coincidence multiplier scheme has been previously reported in a communication to Mr. Chris Gross dated April 21, 1964. Tests on this unit are still incomplete. Some work also remains with respect to additional mechanical and electrical components needed for the permanent attachment of the spectrometer to the main Linac drift pipe (special windows, valves, and remote control programming).

#### Publications and Reports

There were no reports prepared during this period. However a lengthy memorandum dated Feb. 21, 1964 relating to the desirability of making range measurements on low velocity ions was prepared. (letter to C. Gross, NASA-Langley, by F.A. White). This memorandum (1) emphasized the need for additional work in this area and its relation to radiation

damage (2) reviewed the work of other investigators to date, and (3) suggested a specific experimental approach which would bypass the limitations and uncertainties of radio-tracer methods.